

Landscape Features and Spatial Distribution of Adult Northern Corn Rootworm (Coleoptera: Chrysomelidae) in the South Dakota Areawide Management Site

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ABSTRACT The northern corn rootworm, *Diabrotica barberi* Smith & Lawrence (Coleoptera: Chrysomelidae), creates economic and environmental concerns in the Corn Belt. To supplement the population control tactics of the Areawide Pest Management Program in Brookings, SD, geographic information systems were used from 1997 to 2001 to examine the spatial relationships between *D. barberi* population dynamics and habitat structure, soil texture, and elevation. Using the inverse distance weighted interpolation technique, *D. barberi* population density maps were created from georeferenced emergence and postemergence traps placed in maize, *Zea mays* L., fields. For each year, these maps were overlaid with vegetation, soil, and elevation maps to search for quantitative relationships between pest numbers and landscape structure. Through visual interpretation and correlation analysis, shifts in landscape structure, such as size, number, and arrangement of patches were shown to associate with *D. barberi* population abundance and distribution in varying degrees. *D. barberi* were found in greater proportions than expected on loam and silty clay loam soils and on elevations between 500 and 509 m. An understanding of the interactions between *D. barberi* population dynamics and landscape variables provides information to pest managers, which can be used to identify patterns in the landscape that promote high insect population density patches to improve pest management strategies.

KEY WORDS geographic information systems, landscape metrics, population dynamics, spatial analysis, *Diabrotica*

THE NORTHERN CORN ROOTWORM, *Diabrotica barberi* Smith & Lawrence, is a serious pest of maize, *Zea mays* L., in the Corn Belt (Kantack et al. 1970, Metcalf 1986). Traditional control methods include crop rotation and soil insecticides applied at planting. However, insecticides often are used unnecessarily, and this indiscriminant use has promoted environmental (e.g., runoff and groundwater alterations), safety (e.g., handling), and economic concerns (Pimentel et al. 1991, Gray et al. 1993). *D. barberi* also have circumvented crop rotation as a control strategy. Instead of the typical 1-yr diapause, many eggs overwinter for two or more years (Chiang 1965; Krysan et al. 1984, 1986; Levine et al. 1992). Consequently, in a 2-yr crop rotation of maize and another crop, *D. barberi* eggs hatch after 2 yr and larvae then feed on the maize roots. Therefore, the indiscriminant use of insecticides and failure of crop rotation as a consistent and economical means of managing *D. barberi* populations prompted a need for new management tactics.

To minimize the use of insecticides and protect the environment, the United States Department of Agriculture–Agricultural Research Service implemented a corn rootworm areawide pest management program in 1996 (Chandler and Faust 1998, Chandler et al. 2000) in five geographic locations, including four in the Corn Belt and one in Texas (Chandler and Faust 1998, Tollefson 1998, Wilde et al. 1998). The areawide approach relies on management of adult rootworm populations over a wide geographic area applying action thresholds to determine need and appropriate timing for aerial applications of toxic bait formulations that substantially diminish insecticide use (Chandler and Faust 1998). To supplement the areawide approach and to document interactions of edaphic and landscape factors with *D. barberi*, this study focused on analyzing spatial relationships between *D. barberi* population dynamics and habitat structure, soil texture, and elevation. Understanding these relationships is important for directing future pest management decisions at a landscape scale (Landis 1994). For analysis of these relationships, we used geographic information systems to create map layers for visual interpretation and geostatistical analysis of spatial interactions at larger scales (Roberts et al. 1993, Stow 1993). Our objectives were to 1) document shifts

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in maize patches from 1997 to 2001 in relation to *D. barberi* population dynamics and 2) identify the relationships of soil texture and elevation with *D. barberi* populations.

Materials and Methods

Study Area Description. The South Dakota corn root-worm areawide management site was located in the western portion of the Corn Belt (Universal Transverse Mercator coordinates in meters for zone 14N, northwest corner 681127e 4911981n, northeast corner 687618e 4912125n, southwest corner 681317e 4905524w, and southeast corner 687768e 4905671n) in Brookings County, South Dakota. The study site was within the tall grass prairie region of the northern Great Plains (Kaul 1986), encompassed 41.4 km² and was dominated by a mosaic of maize-soybean, *Glycine max* (L.), cropping systems. The site contained ≈60 maize fields and 60 soybean fields of varying size (5–50 ha), depending on the year. We used this management area to characterize the spatial dynamics of *D. barberi* over a 5-yr period (1997–2001).

Trap Collection. Emergence of *D. barberi* populations was monitored weekly by using adult emergence traps (Hein and Tollefson 1985), and Pherocon AM yellow sticky traps (Trécé Inc., Salinas, CA) were used to monitor postemergence adult activity (Tollefson 1986). Both trap types were placed in the maize fields 30–60 m apart along either one or two transects during late June to early July of each year, depending on weather conditions. Postemergence sticky traps were placed in 55–62 maize fields, whereas emergence traps were placed only in 11–16 randomly chosen maize fields, depending on the year. The number of transects, emergence traps, and postemergence traps used in each field varied with field size. For both trap types, 12 were placed in fields ≥47 ha, nine in fields 25–46 ha, six in fields 10–24 ha, and three in fields ≤9 ha. One transect was used in fields ≤24 ha, whereas two transects were used in fields >25 ha and were separated by ≈80 m. The emergence traps (1.0 by 0.6 m) were placed lengthwise directly over five cut plants in the maize row to capture beetles as they emerged from the soil. Postemergence traps (0.2 by 0.3 m) were clamped onto wooden lath strips placed between maize rows in each field. Each postemergence trap was positioned at ear height of the maize plant, or ≈1 m above the soil surface. As beetles flew through the field, they were captured on the adhesive surface of the trap. Beetles from postemergence traps were collected weekly for ≈10 wk, whereas beetles from emergence traps were collected weekly for ≈7 wk.

Georeferencing and Crop Association. Trap and field locations were georeferenced and crop or vegetation types were documented yearly. Vector map layers were created for the study site by using a differential global positioning system. Vector maps portray spatial features as points (traps), lines (roads), and polygons (crop fields) (Bonham-Carter 1994, Johnston 1998). Attribute tables associated with vector maps contain information about the spatial fea-

tures (e.g., trap type). For each year, we imported the variables of field locations, field sizes, crop types, trap locations, trap types, and the number of *D. barberi* adults captured into the attribute tables. Crop types were classified as continuous maize, first-year maize, mixed maize, other maize, and soybean. The soybean classification was deemed important because of the prominence of maize-soybean rotations in the management site. Continuous maize fields were fields that were planted to maize for two or more consecutive years. First-year maize fields were fields planted to a crop other than maize the previous year (usually soybean). Mixed maize fields were those that contained a portion of continuous maize and first-year maize. Other maize fields included sweet maize or maize test plots. Mixed and other maize fields made up only a small portion of the maize planted in the management site and were used only in the “all maize” class-level analyses, and not used in the “patch-level” analyses (see below). Trap types were classified into emergence and postemergence traps.

Interpolation Techniques. Areas of abundance and distribution of *D. barberi* based on emergence and postemergence trapping in maize were characterized as raster map layers with a cell size of 26.4 m per side by using Inverse Distance Weighted interpolation techniques. In contrast to vector maps, raster maps portray spatial features as a matrix of equal-area grid cells containing unique values (Bonham-Carter 1994, Johnston 1998). Interpolation methods calculate predicted variable values for unsampled areas by using georeferenced point sample locations (McCoy and Johnston 2002). The Inverse Distance Weighted method of interpolation estimates the values of sample data points in the vicinity of each cell of the surface map. The closer the point is to the cell center being estimated, the more influence it has in the averaging process. Also with the Inverse Distance Weighted technique, the exponent or power value controls the significance of known georeferenced points upon the interpolated values, based upon the distance from the output point (McCoy and Johnston 2002). A high exponent (3–5) emphasizes points nearer to the interpolated value, whereas a low exponent (0–2) emphasizes points further away from the interpolated value. Using high exponents results in a more detailed, less smooth output surface, whereas using low exponents result in a smoother surface with less detail, respectively (Krajewski and Gibbs 2001). The most commonly used exponent value of two was used, thereby resulting in a smooth raster surface. A variable search radius, with 12 input points was used to allow for variable search neighborhoods, depending on the density of measured points near the interpolated cell (McCoy and Johnston 2002). Although we smoothed over nonpreferred habitat, allowing the distance of the search radius to vary to include the input points reduces their effects with increasing distance on the interpolated cell values. There were several reasons that the Inverse Distance Weighted method was used to estimate beetle abundance. The Inverse Distance Weighted

algorithm allows for rapid calculations, is appropriate for aggregated data and for analyzing short-range variability between scattered data points, and generates quick contour plots for relatively smooth data values (Krajewski and Gibbs 2001).

We used the *D. barberi* interpolated maps to visually analyze their spatial relationships with the vegetation maps. However, describing general relationships in quantitative terms, or mapping the distribution of varying degrees of correspondence between maps would be impossible from visual inspection alone. Therefore, interpolated maps, classified maps of vegetation and the landscape metrics were compared with determine relationships between habitat structure and *D. barberi* population dynamics.

Landscape Metrics. Landscape metrics were calculated using FRAGSTATS software (University of Massachusetts, Amherst, MA) to examine relationships between changes in landscape structure and *D. barberi* population dynamics across the management site. Vegetation (vector) maps were converted into raster maps from which FRAGSTATS calculated class- and patch-level landscape metrics. Patch-level metrics focus on individual fields (i.e., patches) of a particular vegetation type (e.g., all maize or continuous maize), whereas class-level metrics focus on groups of fields of a particular vegetation type (McGarigal et al. 2002). The patch-level metrics included patch area, proximity index of each patch, and the nearest neighbor distance of each patch. The class-level metrics included total class area, percentage of landscape occupied by each class, number of patches in each class, mean patch size of each class, mean proximity index of each class, and mean nearest neighbor distance of each class.

At the class-level, area and percentage of landscape occupied by patches are indicators of landscape composition; specifically, how much of the landscape consists of a particular patch type (McGarigal et al. 2002). In addition, the number and arrangement of patches of a particular habitat type may influence ecological and evolutionary processes within a landscape. For example, the number of patches may determine the number of subpopulations for species exclusively associated with that habitat type, whereas the arrangement of patches may affect dispersal rates and gene flow among the preferred habitats (McCauley 1995, Wiens 1997).

We used nearest neighbor and proximity analyses to determine patch arrangement (McGarigal et al. 2002). Nearest neighbor analysis is calculated by measuring the shortest straight-line distance between the focal patch and its nearest neighbor of the same habitat type. As a measure of patch dispersion, a large standard deviation relative to the mean implies an uneven or irregular distribution, whereas a small standard deviation about the mean indicates a uniform or regular distribution (McGarigal et al. 2002). However, the measure only applies to distances between patches in a cluster, thus ignoring the potentially vast distance between the edge of the cluster and the edge of the map (Hargis et al. 1998).

The proximity index considers size and proximity of all patches whose edges are within a specified search radius of the focal patch (McGarigal et al. 2002). We used a search radius of 800 m to reach beyond the boundary of some large fields. The proximity index determines the spatial arrangement of a habitat patch in relation to its neighbors of the same class; specifically, the index differentiates sparse distributions of small habitat patches from a complex cluster of larger patches. Landscapes with aggregated large patches have higher proximity values than landscapes with dispersed smaller patches (Hargis et al. 1998).

To determine relationships between landscape metrics and *D. barberi* population dynamics, we used correlation analyses between class-level metrics with the seasonal totals and mean number (capture per week per trap) of *D. barberi* captured in postemergence traps, and patch-level metrics with mean number (capture per patch per trap) of *D. barberi* captured in postemergence traps. These analyses were conducted on continuous maize, first-year maize, and all maize classes. For patch-level metrics the all maize class included continuous and first-year maize fields, whereas for class-level metrics the all maize class included continuous, first-year maize, and other maize fields that contained postemergence traps. All data were transformed to $\log_{10}(n + 1)$ to normalize distributions and equalize variances (Zar 1984). Significance of each correlation coefficient was determined from a Fisher r to z transformation (SAS Institute 1998).

Emergence and Postemergence Correlation. *D. barberi* emergence probably correlates with optimal conditions for oviposition and larval survival and should associate with edaphic factors such as soil texture and topography (Tollefson and Calvin 1994). However, because much fewer emergence than postemergence traps were placed in the management site, and postemergence traps encompassed all elevation classes and soil types, we believe the postemergence interpolated maps would provide more accurate estimates of adult *D. barberi* spatial associations with soil texture and elevation. To use postemergence interpolated maps to analyze relationships of *D. barberi* numbers with soil texture, and elevation, we first wanted to determine the relationship between *D. barberi* emergence and postemergence. Two correlation methods were used to evaluate this relationship. The first correlation was computed within ArcInfo software (ESRI, Redlands, CA) by overlaying the interpolated emergence and postemergence map layers (Chou 1997). The second correlation was computed by using the mean number of *D. barberi* beetles captured in emergence and postemergence traps in each patch. This allowed a direct comparison between fields that contained both emergence and postemergence traps. These data also were transformed to $\log_{10}(n + 1)$ (Zar 1984). Significance of each correlation coefficient from interpolated map analysis was determined from a table of critical values of the correlation coefficient (Zar 1984). Significance of each correlation coefficient from the second analysis (tabular data) was determined from a Fisher r to z transformation (SAS Institute 1998).

Table 1. Total and mean (\pm SD) number of *D. barberi* captured per week per trap in postemergence sticky traps and class-level landscape metrics computed for selected vegetation types in the South Dakota corn rootworm areawide management site for years 1997–2001

Vegetation type	Landscape metrics						<i>D. barberi</i>	
	CA	%	NP	Area \pm SD	Prox \pm SD	NN \pm SD	Total	Mean \pm SD
1997								
Continuous maize	316	8	12	26.3 \pm 18.6	28.0 \pm 35.9	555.2 \pm 510.4	6,230	7.7 \pm 9.2
First-year maize	938	23	41	22.9 \pm 18.1	70.8 \pm 75.2	132.1 \pm 149.7	17,448	7.1 \pm 9.1
All maize	1352	33	60	22.3 \pm 18.4	151.6 \pm 139.6	102.9 \pm 113.4	25,765	7.5 \pm 9.3
Soybean	1173	28	55	21.3 \pm 16.8	121.3 \pm 109.6	101.9 \pm 86.9		
1998								
Continuous maize	282	7	10	28.2 \pm 21.9	130.3 \pm 129.5	455.1 \pm 670.2	12,899	21.4 \pm 29.1
First-year maize	962	23	49	19.6 \pm 15.6	87.2 \pm 81.4	115.0 \pm 127.2	20,016	8.8 \pm 13.1
All maize	1370	33	73	18.1 \pm 16.4	142.0 \pm 130.6	78.2 \pm 57.2	35,751	11.6 \pm 18.6
Soybean	1226	30	56	21.9 \pm 17.1	117.5 \pm 94.7	98.8 \pm 113.9		
1999								
Continuous maize	243	6	11	22.1 \pm 20.4	53.0 \pm 82.0	585.5 \pm 793.8	11,117	19.9 \pm 24.5
First-year maize	989	24	43	23.0 \pm 14.4	93.0 \pm 84.9	111.7 \pm 121.1	49,893	22.5 \pm 29.8
All maize	1278	31	60	21.0 \pm 16.1	121.4 \pm 116.9	98.5 \pm 114.5	62,138	21.9 \pm 28.7
Soybean	1211	29	57	21.3 \pm 16.0	113.3 \pm 92.9	89.0 \pm 80.3		
2000								
Continuous maize	158	4	8	19.8 \pm 19.0	8.4 \pm 11.8	439.4 \pm 336.9	4,834	11.3 \pm 12.0
First-year maize	1088	26	48	22.7 \pm 16.0	101.9 \pm 87.0	93.4 \pm 82.3	28,625	10.5 \pm 12.5
All maize	1303	31	59	21.8 \pm 16.1	127.4 \pm 92.1	87.4 \pm 78.5	34,260	10.7 \pm 12.5
Soybean	1291	31	53	24.3 \pm 18.4	149.5 \pm 111.3	80.7 \pm 76.1		
2001								
Continuous maize	78	2	4	19.6 \pm 20.2	0.0 \pm 0.0	979.6 \pm 2.8	2,560	14.3 \pm 13.8
First-year maize	1048	25	42	24.9 \pm 15.8	98.2 \pm 83.9	100.1 \pm 108.0	30,269	13.8 \pm 16.3
All maize	1133	27	48	23.5 \pm 16.5	97.8 \pm 85.2	119.6 \pm 138.8	32,829	13.9 \pm 16.1
Soybean	1225	30	60	20.4 \pm 16.3	113.6 \pm 83.5	72.9 \pm 57.7		

Landscape metrics include cumulative class area (CA), percentage of the landscape occupied (%), number of patches (NP), mean patch size or area (Area \pm SD), mean proximity index (Prox \pm SD), and mean nearest neighbor distance (NN \pm SD).

Contingency Analysis. The soils data covering Brookings County were acquired as a vector map from the United States Geological Survey online Soil Survey Geographic database (www.ftw.nrcs.usda.gov/ssur_data.html). The soil texture map with a scale of 1:24,000 was converted into a raster map with a cell size of 26.4 m per side to match the cell size of the *D. barberi* interpolated maps. The soil map was then classified into five classes that corresponded to soil textures found within the management site. Soil texture classes ranged from least porous to most porous based on the composition of particle size associated with the general soil texture triangle (Buckman and Brady 1969). The texture classes included silty clay, silty clay loam, silt loam, loam, and sandy loam.

The United States Geological Survey Digital Elevation model covering Brookings County was acquired as a raster map from an online database (www.gisdatadepot.com). The data consist of georeferenced digital map and attribute data in a quadrangle format with a scale of 1:24,000 (30 m per side cell size). This elevation map was resampled with 26.4 m per side cell size to match the cell size of the *D. barberi* interpolated maps. The elevation map was then reclassified into a new raster map with five equal-interval elevation classes from 494 to 519 m.

Interpolated raster maps were classified by year into five classes (showing the number of *D. barberi* adults captured per trap). The natural breaks classification scheme was used to identify natural groupings of data based on breakpoints inherent in the data (Abler et al. 1971, Monmonier 1977, Hatakeyama et al. 2000). For

each year, we classified *D. barberi* populations as low, low-medium, medium, medium-high, and high. Because of the variation in number of *D. barberi* captured

Table 2. Correlation coefficients (*r*) and probabilities (*P*) for the relationships between class-level landscape metrics, *D. barberi* postemergence numbers expressed as seasonal totals, and mean capture per week per trap by maize type from the South Dakota corn rootworm areawide management site for years 1997–2001

Maize type	Landscape metric	Total <i>D. barberi</i>		Mean <i>D. barberi</i>	
		<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Continuous	Cumulative area	0.85	0.08	-0.02	0.98
First-year		0.43	0.52	0.31	0.65
All		-0.10	0.89	-0.41	0.53
Continuous	% landscape	0.83	0.09	-0.05	0.95
First-year		0.46	0.48	0.33	0.63
All		-0.08	0.91	-0.40	0.55
Continuous	No. patches	0.82	0.10	-0.06	0.93
First-year		-0.12	0.86	-0.19	0.78
All		0.11	0.88	-0.16	0.82
Continuous	Mean patch area	0.71	0.21	0.09	0.90
First-year		0.41	0.53	0.39	0.56
All		-0.25	0.72	-0.08	0.91
Continuous	Mean proximity index	0.98	<0.002	0.33	0.63
First-year		0.64	0.28	0.58	0.35
All		-0.50	0.43	-0.73	0.19
Continuous	Mean nearest neighbor	-0.67	0.25	-0.01	0.99
First-year		-0.48	0.47	-0.38	0.58
All		-0.11	0.87	0.13	0.85

For each correlation, N is 5 yr.

Maize Fields
1997 South Dakota Areawide Management Site

A



1997 Northern Corn Rootworm Postemergence Distribution

B

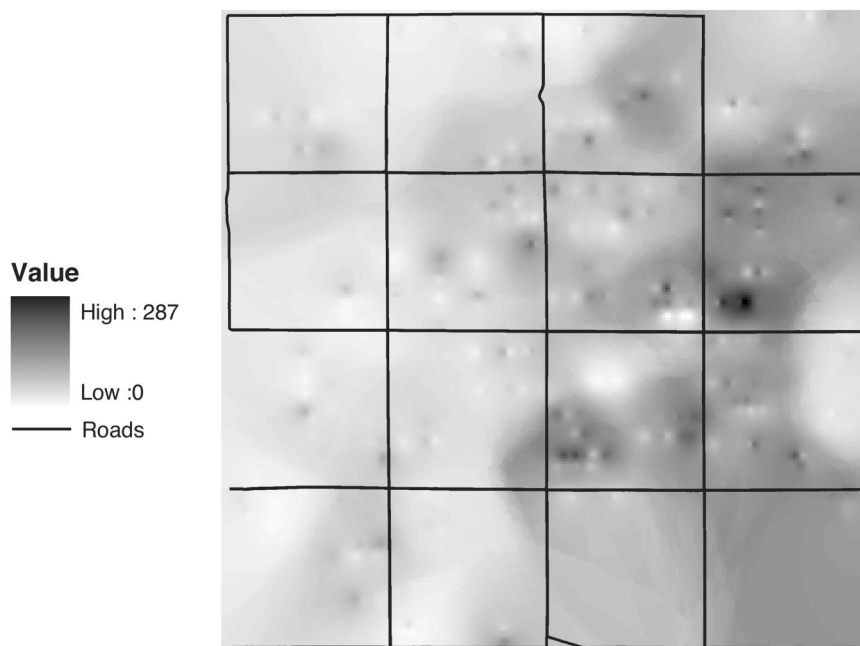


Fig. 1. (A) Vector map illustrating roads and maize fields found in the South Dakota areawide management site in 1997. (B) Raster map illustrating interpolated values of *D. barberi* postemergence trap catches in the South Dakota areawide management site in 1997.

among years, the within class values also varied. Over the 5 yr, low values ranged from 1–54 to 6–99, low-to-medium values ranged from 42–69 to 99–155, medium values ranged from 69–97 to 155–226, medium-to-high values ranged from 97–129 to 226–325, and high values ranged from 129–276 to 325–655. Each of the map layers, soils, elevation, and population, were imported into Idrisi GIS software (Clark Labs-Clark University, Worcester, MA) and masked to display only the soil texture classes, elevation classes, and interpolated values found in maize fields. This was necessary because we were concerned only with the statistical relationships in *D. barberi* preferred habitat and environmental variables.

Within Idrisi, contingency analysis compares the categories of one image (i.e., raster map layer) with those of a second image. We tabulated the frequency of cells in each possible combination of both variables (i.e., population and soil texture or population and elevation) and computed measures of association between the images (Eastman 2001). These measures included χ^2 statistics and Cramer's V coefficients, which indicate the degree of association between the variables (Ott et al. 1983, Siegel and Castellan 1988, Bonham-Carter 1994). Significance of each χ^2 statistic was determined from a table of critical values of the χ^2 distribution (Zar 1984).

Results

Landscape Metrics. The total class area, percentage of landscape, and number of patches occupied by continuous maize decreased from 1997 to 2001. The fewest *D. barberi* captures occurred in 1997, whereas the most were caught in 1999 (Table 1). In regard to continuous maize, neither total nor mean number of *D. barberi* captured correlated significantly with class area, percentage of landscape, or number of patches (Table 2). With the decrease in continuous maize over the 5 yr of our study, there was an associated increase in crop rotation. This resulted in an overall increase in class area, percent occupied, and number of patches of first-year maize and soybean (Table 1). Regarding first-year maize, there were no significant correlations between class area, percentage of landscape, and number of patches with total and mean numbers of *D. barberi* captured (Table 2). In addition, the total and mean number of *D. barberi* captured in first-year corn peaked in 1999 but varied greatly over the 5-yr period (Table 1). The class area, percentage of landscape, and number of patches occupied by all maize peaked in 1998 and were least in 2001 (Table 1). No significant correlations were found between class area, percentage of landscape, and number of patches with total and mean number of *D. barberi* captured in all maize (Table 2).

Mean patch size and mean proximity values for continuous maize peaked in 1998, and then steadily declined through 2001 (Table 1). The mean nearest neighbor values for continuous maize peaked in 2001

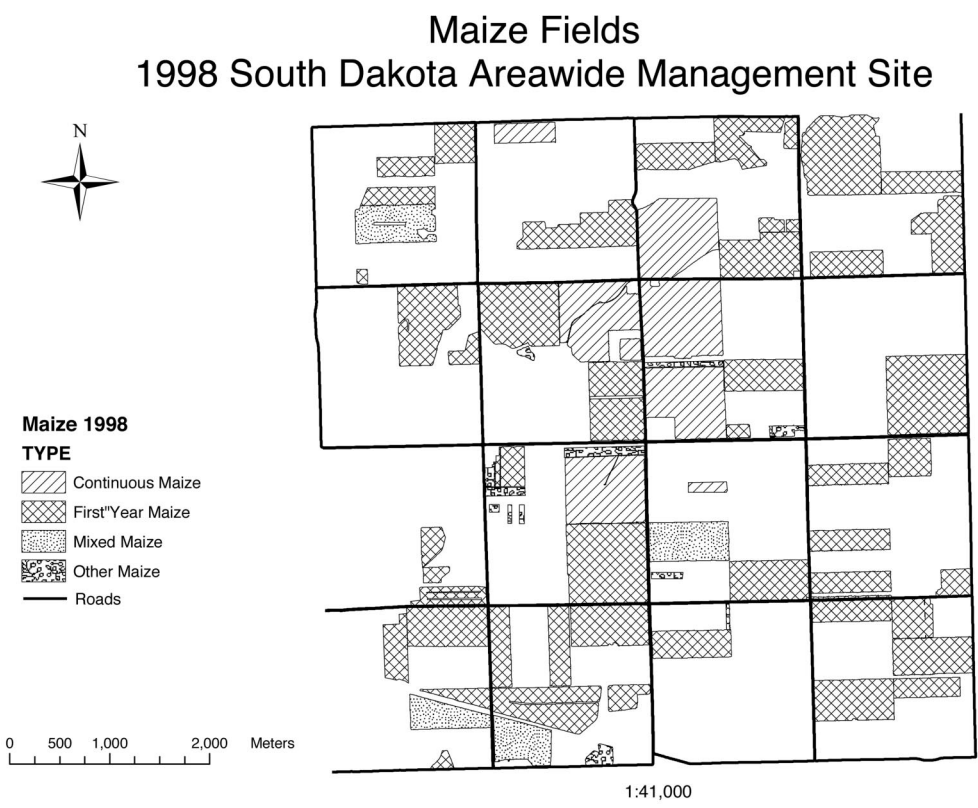
and varied in the four preceding years. For continuous maize, a significant correlation was found only between mean proximity and total number of *D. barberi* captured (Table 2). The mean patch size of first-year maize remained relatively constant over the 5-yr period, with a mean maximum difference of 5.3 ha between 1998 and 2001. The mean proximity value for first-year maize was highest in 2000 and least in 1997, whereas the mean nearest neighbor value was highest in 1997 and least in 2001 (Table 1). Regarding first-year maize, no significant correlations were found between mean patch size, mean proximity, and mean nearest neighbor with total and mean number of *D. barberi* captured (Table 2). Similar to first-year maize, the mean patch size for all maize also remained relatively constant over the 5-yr period, with a mean maximum difference of 5.4 ha between 1998 and 2001 (Table 1). The mean proximity value for all maize was highest in 1997 and least in 2001, whereas the mean nearest neighbor value was highest in 2001 and least in 1998 (Table 1). For all maize, no significant correlations were found between mean patch size, mean proximity, and mean nearest neighbor with total and mean number of *D. barberi* captured (Table 2).

By visually inspecting and comparing the interpolated *D. barberi* population raster maps to the classified vegetation maps over the 5-yr period, it is evident that the spatial distribution of *D. barberi* in the management site was concentrated in large maize patches, especially those adjacent to other maize patches (Figs. 1–5). Note that as the distribution of maize patches shifted in the management site over the 5-yr period, the corresponding distribution of *D. barberi* also shifted. This is partially corroborated by the significant class-level correlation between mean proximity values and total number of *D. barberi* captured in continuous maize (Table 2). Further evidence is indicated by the significant patch-level correlations between postemergence captures in continuous maize, first-year maize, and all maize with patch area (Table 3).

Contingency Analysis. We found significant correlations between *D. barberi* emergence and postemergence interpolated maps for all 5 yr (Table 4). We also found significant correlations between mean numbers of *D. barberi* captured from emergence and postemergence traps for each of the 5 yr (Table 4). The correlation coefficient also was significant over all 5 yr ($r = 0.72$, $df = 60$, $P = < 0.0001$). Therefore, we used postemergence interpolated maps to determine relationships of soil texture and elevation with beetle numbers.

Loam was the most common soil texture class (47.7%) in the management site, followed by silty clay loam (31.4%), silty loam (17.7%), sandy loam (2.9%), and silty clay (0.3%). These percentage soil classes were similar for maize growing areas over the 5-yr management period (Fig. 6). Populations of *D. barberi* occurred most frequently on loam soils, followed by silty clay loam and silt loam (Table 5). Contingency analysis revealed highly significant associations between soil texture and *D. barberi* abundance for each

A



B

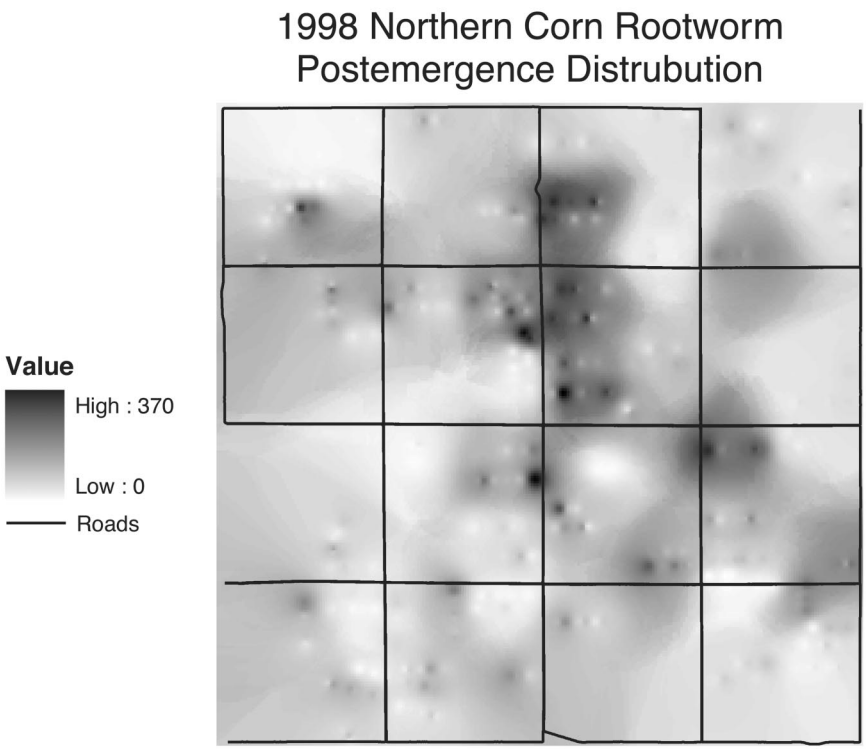


Fig. 2. (A) Vector map illustrating roads and maize fields found in the South Dakota areawide management site in 1998. (B) Raster map illustrating interpolated values of *D. barberi* postemergence trap catches in the South Dakota areawide management site in 1998.

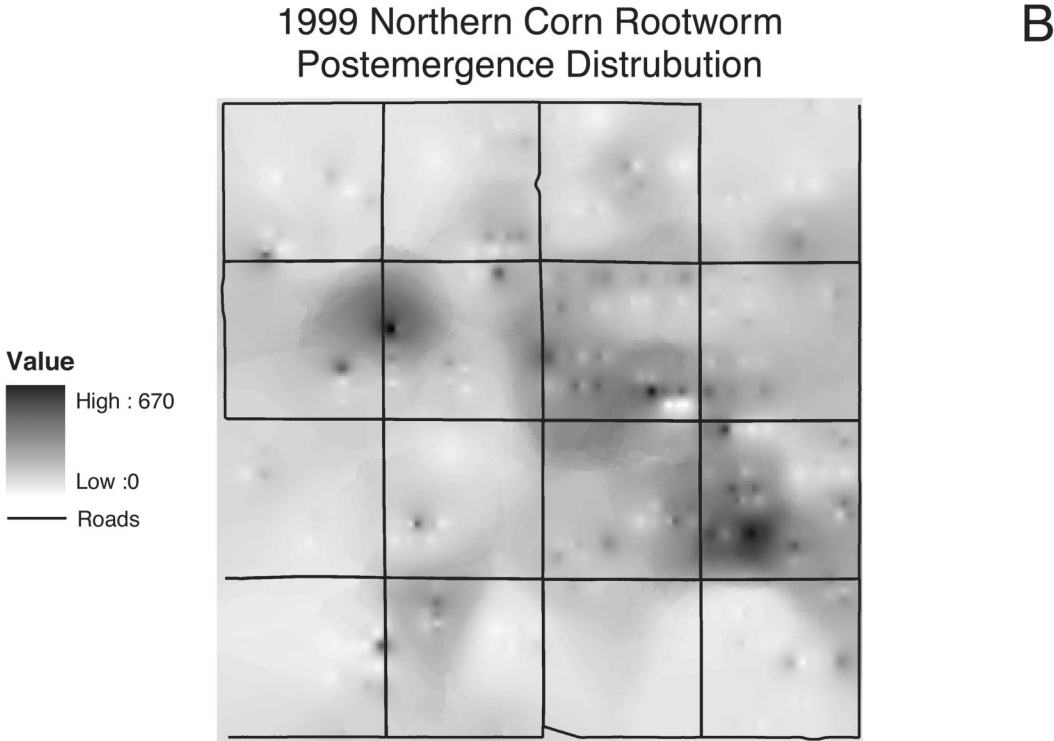
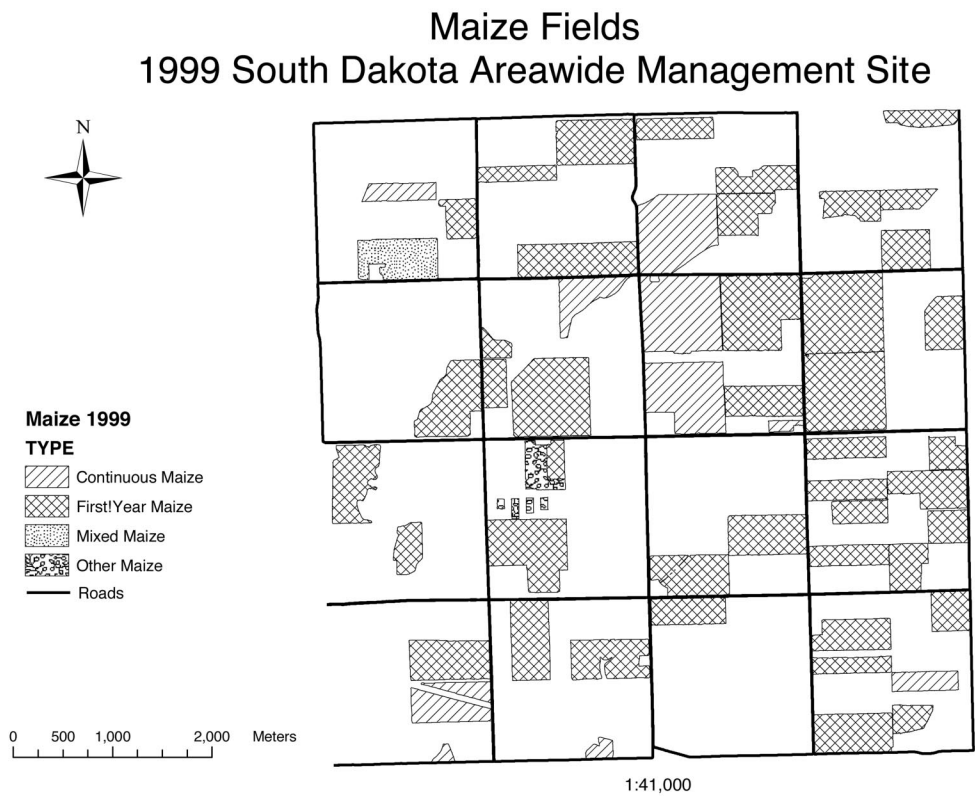
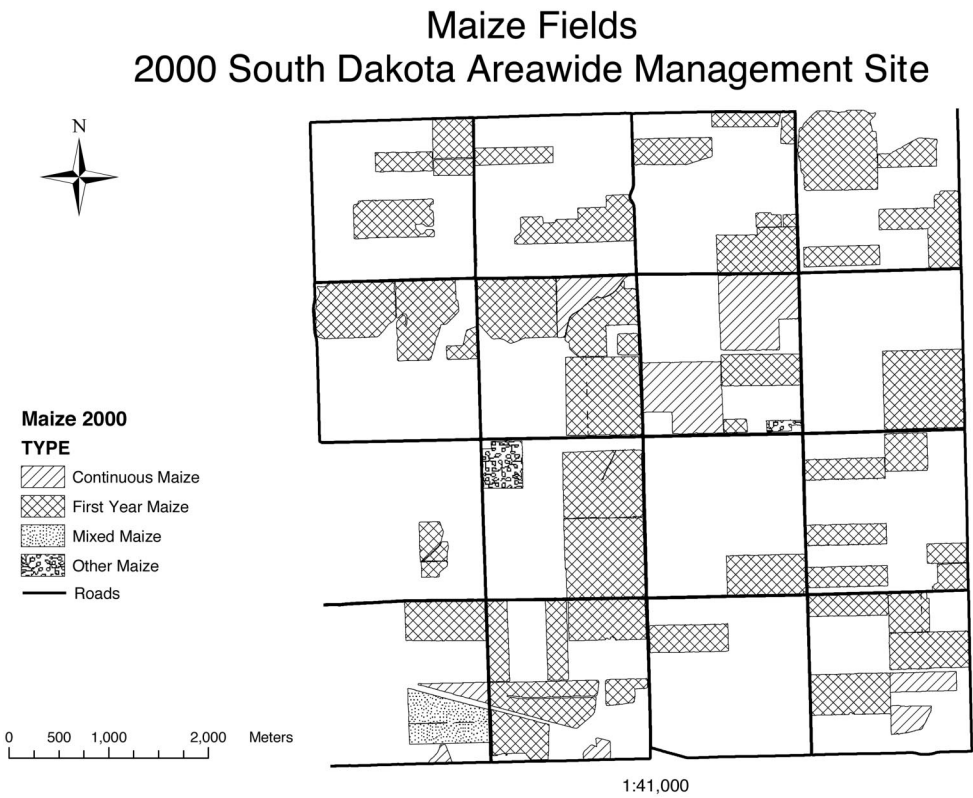


Fig. 3. (A) Vector map illustrating roads and maize fields found in the South Dakota areawide management site in 1999. (B) Raster map illustrating interpolated values of *D. barberi* postemergence trap catches in the South Dakota areawide management site in 1999.

A



B

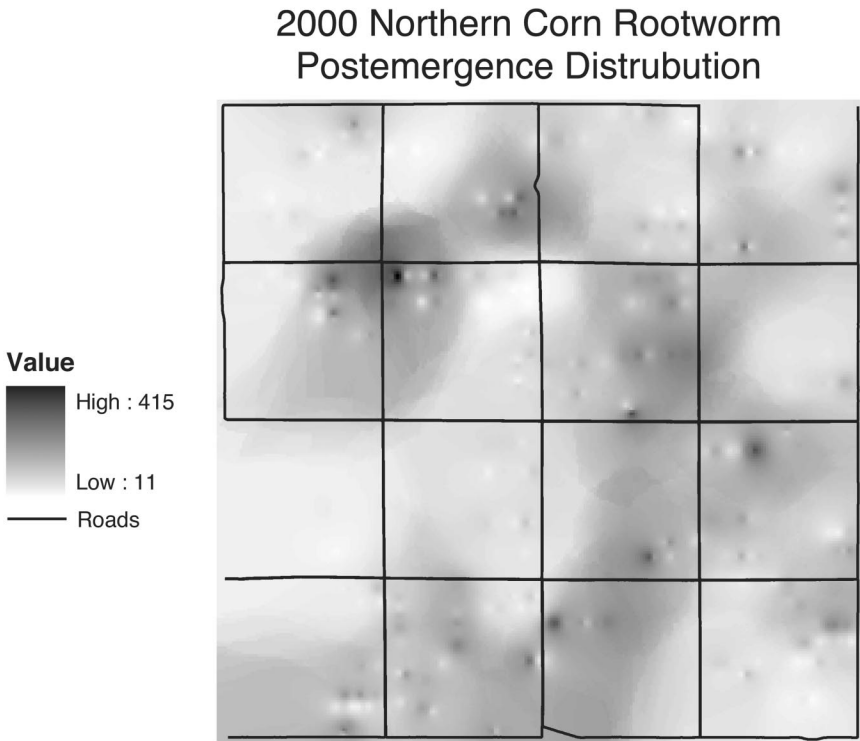


Fig. 4. (A) Vector map illustrating roads and maize fields found in the South Dakota areawide management site in 2000. (B) Raster map illustrating interpolated values of *D. barberi* postemergence trap catches in the South Dakota areawide management site in 2000.

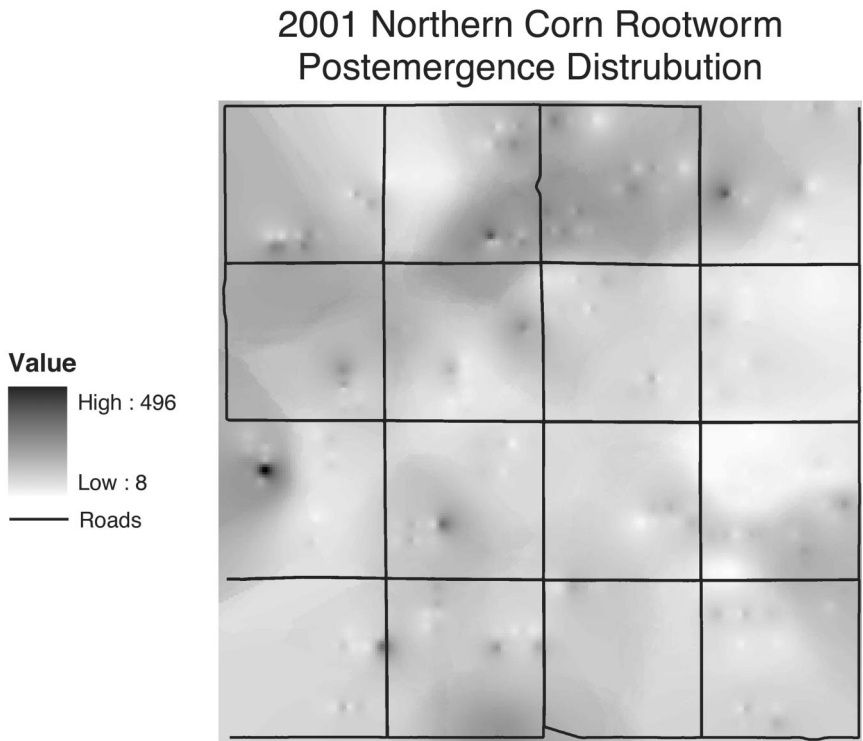
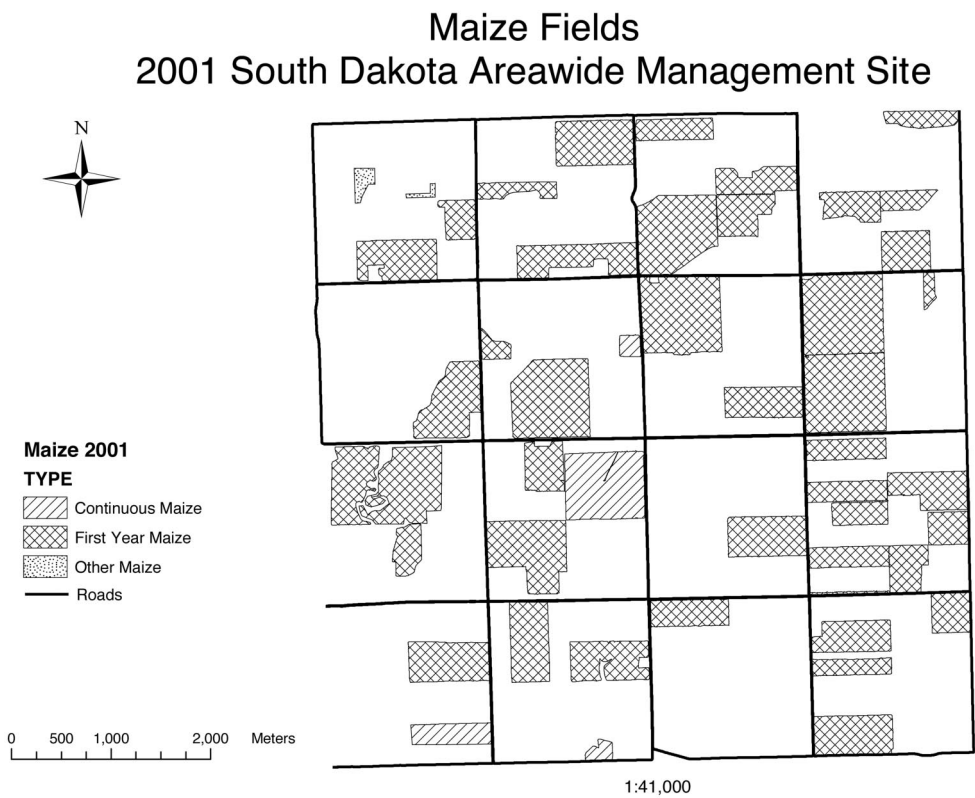


Fig. 5. (A) Vector map illustrating roads and maize fields found in the South Dakota areawide management site in 2001. (B) Raster map illustrating interpolated values of *D. barberi* postemergence trap catches in the South Dakota areawide management site in 2001.

Table 3. Correlation coefficients (r) and probabilities (P) for the relationships between patch-level landscape metrics with mean no. of *D. barberi* postemergence captured per patch per trap by maize type from the South Dakota corn rootworm areawide management site for years 1997–2001

Maize type	Landscape metric	N	r	P
Continuous	Patch Area	44	0.33	0.03
First-year		220	0.27	<0.001
All		264	0.28	<0.001
Continuous	Proximity index	44	0.02	0.88
First-year		220	0.05	0.46
All		264	0.05	0.45
Continuous	Nearest neighbor	44	−0.03	0.85
First-year		220	<0.01	0.93
All		264	<0.01	0.97

N is number of fields from 1997 to 2001.

year, as indicated by χ^2 values (Table 6). The strength of the association was greatest in both 1997 and 1999 and least in 1998 as indicated by Cramer's V coefficients (Table 6).

The most common elevation class in the management site was 500–504 m (34.6%) followed by 494–499 m (24.1%), 505–509 m (22.4%), 510–514 m (17.7%), and 515–519 m (1.2%). However, the percentage of these elevation classes varied for maize growing areas over the 5-yr management period (Fig. 7). Maize-growing areas occurred less frequently at elevations between 494 and 499 m, and more frequently between 505 and 514 m. Beetle densities were greatest at elevation classes 500–504 m and 505–509 m (Table 7). Contingency analysis revealed highly significant associations between elevation class and *D. barberi* abundance for each year, as indicated by χ^2 values (Table 8). The strength of the association was greatest in both 1997 and 1999 and least in 1998 as indicated by Cramer's V coefficients (Table 8).

Discussion

Basic structural characteristics of the landscape can affect species abundance and distribution (Turner 1989, Wiens 1997, McGarigal et al. 2002). The abundance and distribution of many species can be strongly

Table 4. Correlation coefficients (r) and probabilities (P) for the relationships between *D. barberi* emergence and postemergence interpolated map layers and between *D. barberi* mean emergence and mean postemergence (Tabular) from the South Dakota corn rootworm areawide management site for years 1997–2001

Year	Interpolated maps			Tabular		
	N	r	P	N	r	P
1997	62,750	0.93	<0.001	10	0.89	<0.001
1998	62,750	0.86	<0.001	11	0.82	0.001
1999	62,750	0.70	<0.001	14	0.72	<0.003
2000	62,750	0.88	<0.001	11	0.80	<0.002
2001	62,750	0.43	<0.001	15	0.81	<0.001

Degrees of freedom is number of observations (N) − 2.

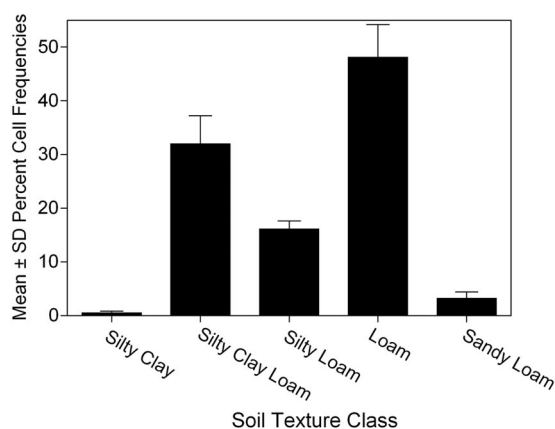


Fig. 6. Mean (\pm SD) percentage of cell frequencies for soil texture classes where maize was grown in the South Dakota areawide management site from 1997 to 2001.

correlated with the total area and number of patches of preferred habitat within the context of the landscape (Forman and Godron 1986, Robbins et al. 1989, Andr n 1994, Gustafson et al. 1994, Forman 1995, McGarigal and McComb 1995). In this study, total and mean *D. barberi* abundance did not correlate with class area, percentage of landscape, or number of patches for continuous maize, first-year maize, and all maize. However, because probability values were close to significance, total *D. barberi* abundance may have correlated with these landscape metrics for continuous maize had more years been sampled. If so, this would be similar to the significant relationships between these landscape metrics and total abundance of *Diabrotica virgifera virgifera* LeConte for continuous maize (Beckler et al. 2004). Unlike *D. barberi*, however, Beckler et al. (2004) found that *D. v. virgifera* total and mean abundance correlated with class area, percentage of landscape, and number of patches for all maize. They suggested that *D. v. virgifera* are dispersing from continuous maize, which acts as a primary source for *D. v. virgifera* populations, into first-year maize or sink habitats. These differences between *D. barberi* and *D. v. virgifera* may be due, in part, to extended diapause of *D. barberi* eggs (Chiang 1965, Krysan et al. 1984, Levine et al. 1992). Up to 40% of the eggs of these beetles are capable of overwintering for 2 yr, instead of the typical single year egg diapause (Krysan et al. 1984). Thus, in areas where extended diapause is prominent, a 2-yr crop rotation has proven ineffective as a population control strategy for this insect. Consequently, we do not find the variability in numbers of *D. barberi* associated with all maize fields to correlate with these descriptive class-level metrics.

Large aggregated patches may support higher densities than smaller dispersed patches (Harrison and Taylor 1997, Wiens 1997). For example, Thomas and Hanski (1997) found that large habitat patches in proximity had a higher frequency of the skipper butterfly *Hesperia comma* L. than smaller, more isolated

Table 5. Percentage of cell frequencies for contingency χ^2 analyses of the relationships between soil texture and interpolated *D. barberi* abundance maps from the South Dakota corn rootworm areawide management site for years 1997–2001

Abundance	Soil texture class				
	Silty clay	Silty clay loam	Silty loam	Loam	Sandy loam
1997 (19,240)					
Low	0.01	4.56	6.19	23.93	2.38
Low–medium	0.06	7.70	5.83	14.50	0.50
Medium	0.04	9.38	2.23	3.75	0.01
Medium–high	0	11.46	2.26	0.84	0
High	0	3.16	0.46	0.22	0
1998 (19,654)					
Low	0.14	10.21	6.92	21.86	1.58
Low–medium	0	4.75	5.22	18.53	0.61
Medium	0.38	4.39	3.85	6.36	0.19
Medium–high	0.19	4.98	1.37	3.46	0
High	0	1.69	0.83	2.48	0
1999 (18,214)					
Low	0.42	2.31	5.76	19.37	4.08
Low–medium	0.26	12.20	7.66	12.57	0.19
Medium	0.01	12.74	1.80	6.00	0.01
Medium–high	0	8.59	0.21	3.41	0
High	0	1.86	0.02	0.55	0
2000 (18,677)					
Low	0.12	5.28	9.29	23.22	1.29
Low–medium	0.41	7.96	2.10	12.35	0.34
Medium	0	8.52	0.67	11.69	0.13
Medium–high	0	4.20	1.65	6.32	0.01
High	0	1.30	0.71	2.45	0
2001 (16,209)					
Low	0	18.00	1.14	7.16	0.69
Low–medium	0	8.45	7.63	17.60	2.35
Medium	0	5.26	3.84	11.32	1.22
Medium–high	0.32	1.24	2.92	10.24	0.24
High	0	0.04	0.04	0.32	0

Total number of cells is in parenthesis by year.

patches. Similarly, Smith and Gilpin (1997) found that in all cases for the American pika, *Ochtona princeps* Richardson, the average size of occupied patches was greater than the average size of vacant patches. Maize fields in the areawide management site of our study varied in size and arrangement over the 5-yr period. More *D. barberi* were captured on postemergence traps in the larger maize patches. Also, through visual map interpretation, nearest neighbor analyses, and proximity analyses, we showed that maize patches shifted in size and dispersion patterns in the management site over the 5-yr period. Also through visual map interpretation, *D. barberi* abundance shifted with the availability of maize patches. Similar to *D. v. virgifera* (Beckler et al. 2004), this association seemed especially true for large continuous maize patches, as supported by the positive class-level correlation between

Table 6. Contingency χ^2 analyses of the relationship between soil texture and *D. barberi* abundance from the South Dakota corn rootworm areawide management site for years 1997–2001

Year	χ^2	Cramer's V	P
1997	6607	0.29	<0.001
1998	1506	0.14	<0.001
1999	5845	0.28	<0.001
2000	2131	0.17	<0.001
2001	3839	0.24	<0.001

For each χ^2 , df = 16.

D. barberi total abundance and proximity indices of continuous maize.

In addition to structural characteristics of landscape configuration, edaphic factors can influence the distribution of populations. For example, the microhabitat of a preferred oviposition site for female corn rootworms is influenced by soil properties such as type, texture, moisture content, and compaction (Kirk et al. 1968, Ruesink 1986). The distribution and abun-

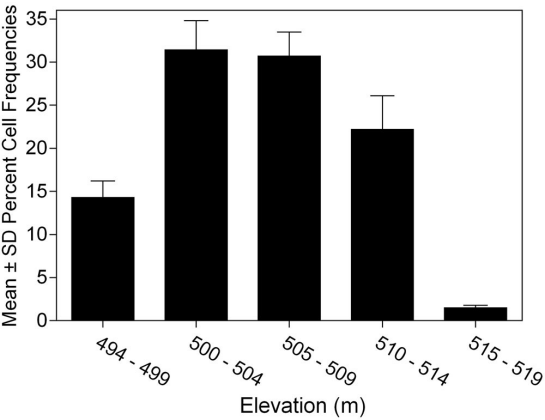


Fig. 7. Mean (±SD) percentage of cell frequencies for elevation classes where maize was grown in the South Dakota areawide management site from 1997 to 2001.

Table 7. Percentage of cell frequencies for contingency χ^2 analyses of the relationships between elevation and interpolated *D. barberi* abundance maps from the South Dakota corn rootworm areawide management site for years 1997–2001

Abundance	Elevation (m)				
	494–499	500–504	505–509	510–514	515–519
1997 (19,240)					
Low	10.37	12.30	11.38	3.01	0
Low–medium	1.66	8.03	11.99	7.32	0.11
Medium	0.18	3.42	4.73	6.68	0.40
Medium–high	0.03	2.95	3.67	7.36	0.56
High	0	0.50	1.48	1.81	0.05
1998 (19,654)					
Low	6.41	14.21	11.25	7.52	1.33
Low–medium	6.85	12.23	7.12	2.78	0.13
Medium	1.19	4.77	5.84	3.04	0.34
Medium–high	0.04	1.65	4.52	3.77	0.03
High	0	1.14	2.29	1.56	0
1999 (18,214)					
Low	10.26	8.80	9.59	3.30	0
Low–medium	2.31	10.08	11.36	8.94	0.19
Medium	0.34	5.50	6.32	7.48	0.91
Medium–high	0.07	2.75	2.84	6.46	0.09
High	0	1.55	0.43	0.45	0
2000 (18,677)					
Low	4.70	14.16	15.68	4.60	0.05
Low–medium	3.77	6.17	5.85	6.13	1.24
Medium	6.14	6.21	3.54	4.66	0.47
Medium–high	2.06	5.84	0.79	3.45	0.04
High	0.43	2.74	0.31	0.98	0
2001 (16,209)					
Low	2.26	2.66	10.68	10.05	1.33
Low–medium	7.69	11.04	10.90	6.38	0.01
Medium	2.40	12.17	4.37	2.69	0
Medium–high	2.16	5.92	6.51	0.37	0
High	0.19	0.10	0.07	0.04	0

Total number of cells is in parenthesis by year.

dance of adult *D. barberi* in the management site was highly associated with both soil texture and elevation. Identical to findings for *D. v. virgifera* (Beckler et al. 2004), we found *D. barberi* in greater proportions than expected on loam and silty clay loam soils and on elevations between 500 and 509 m. The variability in soil texture at our site was comparable to a laboratory study that showed larval survival rates of *D. v. virgifera* and *Diabrotica undecimpunctata howardi* Barber, depended on the clay percentage of the soil and porosity, both functions of soil texture (Turpin and Peters 1971).

Traditionally, managing pest insect populations in agricultural ecosystems has occurred at the farm rather than the landscape scale (Landis et al. 2000). The areawide approach to managing corn rootworm

populations incorporated the broader landscape approach to pest management. Even though only a few landscape metrics were computed in this study, a small set of landscape indices captured significant aspects of shifting patterns of vegetation and *D. barberi* abundance. In addition, we could have underestimated some of the relationships of landscape composition and *D. barberi* distribution because mortality from insecticide application was not accounted for. Further research at other areawide sites that vary in landscape structure, soil textures, and elevation may be useful to determine the significance of these variables on *D. barberi* and *D. v. virgifera* metapopulation dynamics across the Corn Belt. Overall, our research emphasizes the potential role for geographic information systems to provide information on interactions between landscape structural characteristics, edaphic factors, and insect population dynamics. Geographic Information Systems can be used in research to find patterns in the landscape that promote high insect population density patches and ultimately to improve pest management strategies. Landscape planners, agricultural managers, and producers can benefit from this research by understanding the complex interactions of *D. barberi* population dynamics and landscape variables.

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Table 8. Contingency χ^2 analyses of the relationship between elevation and *D. barberi* abundance from the South Dakota corn rootworm areawide management site for years 1997–2001

Year	χ^2	Cramer's V	P
1997	5097	0.26	<0.001
1998	2445	0.18	<0.001
1999	4551	0.25	<0.001
2000	2889	0.20	<0.001
2001	3810	0.24	<0.001

For each χ^2 , df = 16.

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